Semiconductors & Defects: Exercise 3 (15 Nov. '22)

General remark: Always try to come up with a short answer that catches the essence.

3. Discussion and drawing: What is the special significance of the Brillouin zones? Assuming a regular 1D chain of atoms, explain why an electron (treated in the nearly free particle approximation) exhibits two energy values at $\boldsymbol{k} = \boldsymbol{k}_{BZ}$ ($\boldsymbol{k}$: wave vector). Draw the $E(\boldsymbol{k})$ diagram for (i) the free electron gas and (ii) the free electron gas with diffraction at the first Brillouin zone edge. What is the advantage of the reduced zone scheme?

5. Calculation: Show that the width of the "soft zone" of the Fermi–Dirac distribution $f(E)$ is approximately $4k_BT$. [Hint: Use the tangent to $f(E)$ at $E = E_F$.]

6. Formulae and discussion: Using the relevant formula, explain how the carrier density in an energy interval depends on the density of states (DOS) and on the Fermi–Dirac distribution function. What is the difference between the true DOS function, $D(E)$, and the effective density of states, N_{eff}? For which condition is the latter a good approximation to the former? Mathematically speaking, in which way does N_{eff} simplify the equations needed to describe a semiconductor (SC)? In physics terms, how does the usage of N_{eff} simplify the thinking about the electronic transitions taking place in a SC?

8. Discussion: Lift the seeming contradiction between the images shown on the second page by explaining how this geometric paradox "works."

   (Remarks: This is an off-topic task, deliberately introduced here just for to train both your ability to catch the essence as well as your logical argumentation skills. The key word in this task is "explaining" – think about what makes a statement an essence-catching explanation.)

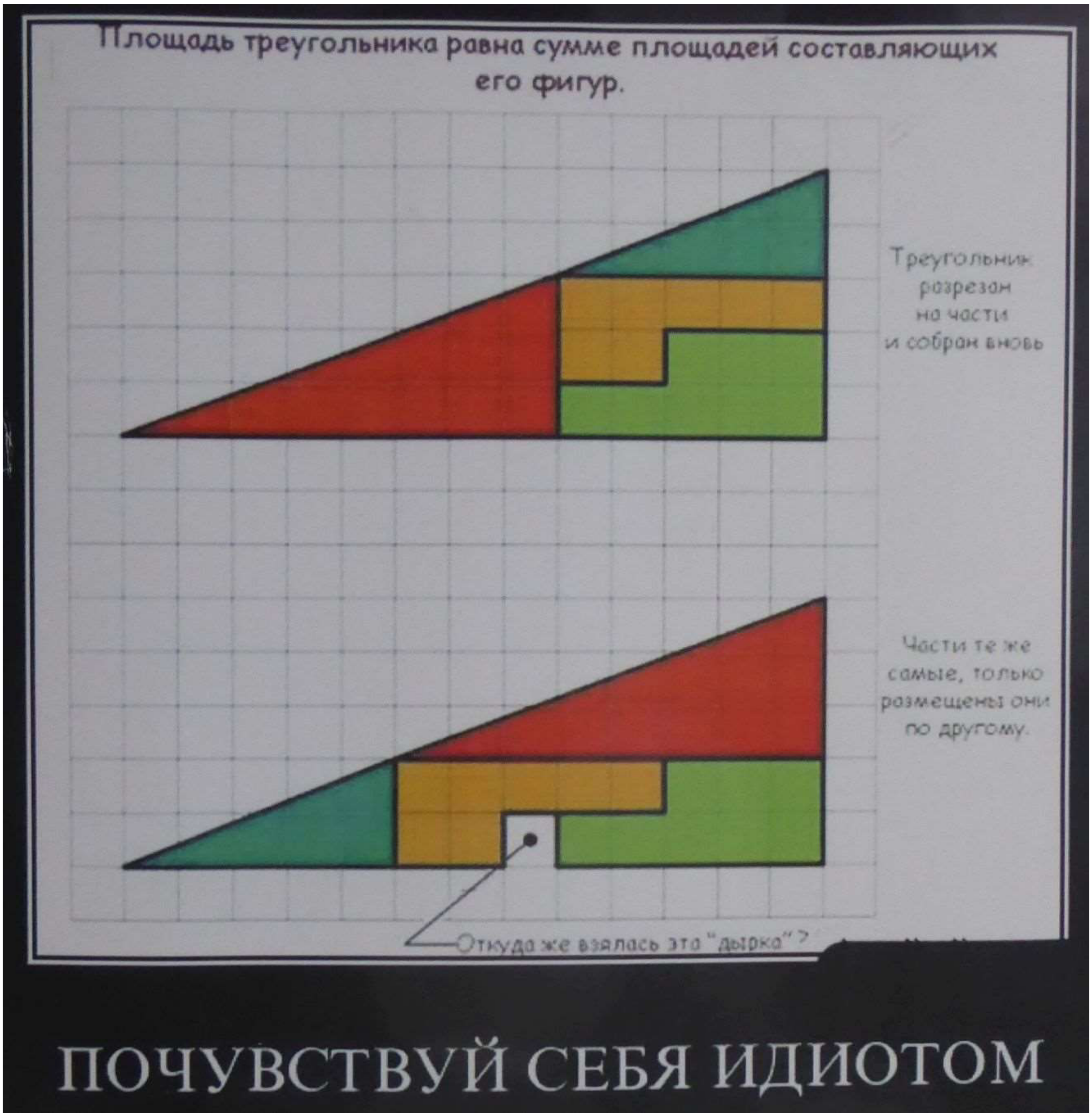
9. Discussion, drawing, and formula: What is meant by an "extrinsic semiconductor"? Draw the schematic band diagram of an extrinsic SC having conduction band, valence band, donor level, and acceptor level. Specify the charge neutrality condition in an extrinsic SC, and explain why the various charges are counted this way. Which important quantity can be obtained from this condition (for a given temperature)?

10. Discussion and numbers: Generally speaking, what are "minority charge carriers"? Why do we have minority charge carriers in a doped SC, but not in an intrinsic one? What are the majority and minority charge carriers in a p-type and an n-type SC? How can one make Si n-type or p-type? By how many orders of magnitude may differ the density of the majorities from that of the minorities (roughly)? How to find the minority charge carrier density in a doped SC if the doping level and n_i are known?

11. Discussion: What are semiconductors (SCs) in general, and by which "condition" are only some of them (in principle; there are a few exceptions) of technological relevance? Explain the main differences between metals, semiconductors and insulators. Give examples for different kinds of SCs that can be formed by elements of the periodic table.

12. Formulae and discussion: Explain the quantity "mobility": How is it defined, and how can it be written in the simple scattering time approximation – and why so? What are the main factors affecting the mobility of charge carriers, and in which way? How can

these effects be understood on the basis of the model of nearly free electrons? How do these effects depend on temperature – and why so?



By the way, the Cyrillic text is Russian, the line below meaning “feel like an idiot”, while the headline tells “The area of a triangle is equal to the sum of the areas of the figures that make up the triangle.” On the right it says “The triangle has been cut into pieces and reassembled again” and “The parts are the same, only they are placed differently”. Finally, there is the question “Where did the hole come from?”